Application of Modern Biotechnology for Improving Livelihoods in the Semi-Arid Tropics -- ICRISAT's Initiatives

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Abstract

By the year 2020) the global population is expected to reach 8 billion. Conventional methods of crop production alone cannot feed so many hungry mouths. Despite the successes of the Green Revolution, the battle to ensure food security for hundreds of millions is far from won. Agricultural biotechnology has the potential to reduce crop losses from pests and diseases; improve the nutrient efficiency of food and animal feeds; extend the post-harvest life of fruits and vegetables; and to increase the stress tolerance of crop plants allowing them to tolerate various environmental extremes. In developing countries in particular, biotechnology has the potential to revitalize the agricultural sector and increase the profitability of farming. Scientific solutions to improve crop productivity, where biotechnology can play an important role, can empower the rural sector by boosting food production, enhancing income for the small farmer, and improving his nutritional security. This paper demonstrates that appropriate technology holds the key to sustainable crop productivity, food security, and poverty alleviation in resource-poor developing countries. It examines the tools of biotechnology ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) employs in its journey from a Grey to a Green Revolution, ultimately leading to agricultural transformation and economic growth and improved livelihoods for millions in the resource-poor regions of SAT (semi-arid tropics).

Introduction

As 100 million new people are added to the world's population each year, will Robert Malthus' prediction of increasing food scarcity come true? Will food scarcity, hunger and disease related to malnutrition become even more widespread in the next 20–30 years? The world population is predicted to reach 8 billion by the year 2020) . The population increase in developing countries alone constitutes 97% of the global increase (Swaminathan 1995). Feeding 3 billion additional people will require dramatic increases in crop production, a formidable task by any standard (Borlaug 1983).

Poverty continues to limit access to food, leaving hundreds of millions of people hungry and undernourished in developing countries. A burgeoning population, income growth, and urbanization threaten to drive sustained growth in food demand, leading to enhanced food needs. The yields of several crops have already plateaued in developed countries, and therefore, most of the productivity gains in the future will have to be achieved in developing countries through better management of natural resources and crop improvement.

Over the past century, conventional plant breeders and related scientists have worked diligently and skillfully to upgrade quality and raise yields by employing various crop improvement techniques with commendable results. The Green Revolution was one of the greatest achievements that led to the phenomenal increase of research-based agricultural productivity, which fed millions in many poor countries, especially on the Indian subcontinent. However, Africa has lagged behind in reaping the benefits of the Green Revolution on account of the limited use of high-yielding varieties of maize, wheat, and rice in the continent (Brink, Woodward and DaSilva 1998). Africa, unlike any other region in the world, has the lowest average crop production per unit area of farmed land. Any factor therefore, which destabilizes the performance of agriculture leads to direct and severe consequences for the well being of the people. These low yields per hectare frequently result in severe food deficits, which often lead to mass starvation or large food imports (Wambugu 1999).

Resource-poor farmers of the SAT regions of the world, including Saharan and sub-Saharan Africa, undertake 60% of the global agriculture, but produce only 15%–20% of the world's food. The major factor underlying the low crop production is frequent rainfall failures, which directly translate into severe droughts and massive crop failures. Their farmlands are in fragile environments that are low in fertility and productivity, where crops face major challenges from biotic and abiotic stresses and limited access to external inputs like irrigation, fertilizers, and pesticides. To these people, agriculture means growing marginal crops on marginal lands with marginal resources, with low productivity. The majority of the people thus live in abject poverty (Ndiritu 1999).

To combat these crises, SAT more than any other region urgently needs technologies that enable agriculture to reduce losses, increase yields, and minimize environmental impact. The development and promotion of modern, high-yielding varieties was the most important factor contributing to this success. Notwithstanding these impressive gains, there are limitations to the conventional plant-breeding technology either due to the limited gene pool or the restricted range of plant species between which genes can be transferred due to species barriers (Borlaug 2000).

The technological challenge therefore lies in obtaining improvements in agricultural productivity without destroying the global natural resource base. New technologies, such as biotechnology, if properly focused, offer a responsible way to enhance agricultural crop productivity. Five key factors are required for improved crop production, i.e., use of appropriate agrochemicals, sustainable irrigation, efficient high-yielding (adapted) varieties, crop management, and plant biotechnology. Choosing not to be integrative can be counter-productive to the goal of sustainable food security for the poor in the developing world. The newly acquired ability to transfer genes between organisms without sexual crossing provides breeders with new opportunities to improve the efficiency of production and to increase the utility of agricultural crops. While new tools, technologies, and products will come from the rapid advances in molecular biology and genetic engineering, the science that made the Green Revolution possible remains important today. However, with the rapid development of plant biotechnology, agriculture can be efficiently moved from a resource-based to a science-based industry (Sharma and Ortiz 2000).

Agricultural biotechnology provides modern ideas and techniques to complement agricultural research by employing the tools of modern genetics to enhance the beneficial traits of plants, animals, and microorganisms for food production. Biotechnological applications in plant breeding offer an unprecedented range of choices for making the future of agriculture more productive and sustainable. The requirement for such approaches is considered in the context of the need for more food for the poor. Modern plant-breeding methods may help to achieve productivity gains, strengthen resistance to pest and diseases, reduce pesticide use, improve crop tolerance for abioticstress, improve the nutritional value and enhance the durability of products during harvesting and storage. Rise in productivity could increase smallholder's incomes, reduce poverty, increase food access, reduce malnutrition, and improve the livelihoods of the poor. Since the limited variability in the available germplasm is a constraint to crop improvement, future breakthroughs depend on creating additional variability and inflow of desirable genes from related or unrelated species (Sharma and Ortiz 2000).

With the advent of gene transfer technology, there is hope for achieving higher productivity and better quality, including improved nutrition and storage properties of food. Several transgenic cultivars of major food crops, such as soybean, maize, canola, potato, and papaya, have been commercially released incorporating genes for resistance to herbicides, insects, and viruses. It is estimated that the global area planted with transgenic crops has risen from 1.7 million hectares in 1996 to 90 million hectares in 2005 (James 2005).

The 'Grey to Green Revolution' concept of ICRISAT aims to turn the adversities of dry-land agriculture into opportunities. For harnessing science-based agricultural development, ICRISAT focuses mainly on SAT, a fragile ecosystem where agriculture is the backbone of several economies. Poverty, food insecurity, child malnutrition, and gender inequalities are widespread in SAT regions.

Over 80% of the total SAT poor (and one-third of the total poor in the developing world) live in sub-Saharan Africa and South Asia (Ryan and Spencer 2001). However, this new revolution to green the grey areas is not possible without the modern tools of science such as biotechnology and information technology. Biotechnology has the potential to substantially increase the rates of return on investments in genetic improvement. Moreover, there are synergies between advances in DNA (deoxyribonucleic acid) sequencing, genome analysis, and bioinformatics. Information is a vital resource for farmers to take well-informed and timely decisions to make optimal use of available resources, together with new science tools such as GIS (geographical information systems) and modelling.

In its efforts to help developing countries in SAT attain food security and reduce poverty and malnutrition, ICRISAT places special emphasis on the genetic enhancement of five crops — sorghum, pearl millet, groundnut, chickpea, and pigeonpea — that are particularly important in the diets of the poor. Participatory and interdisciplinary research has resulted in the development of an IGNRM (integrated genetic and natural resource management) approach.

The changing scenario of agriculture guides ICRISAT's dynamic genetic enhancement priorities and strategies. Improved yield potential is its most important breeding objective, followed by genetic improvement for resistance/tolerance to diseases, insect-pests, abiotic stresses, adaptation, and quality of grain and fodder. It recognizes that traditional germplasm resources are vital to crop improvement, hence its R S Paroda Genebank conserves genetic resources of sorghum, pearl millet, chickpea, pigeonpea, groundnut, and six small millets, holding 114 870 accessions of these crops from 130 countries. It has been supplying over 40 000 germplasm samples annually to scientists globally, of which about 30% have been shared with scientists of the Indian national programme, resulting in the release of 570 varieties. ICRISAT's global collection also serves the purpose of restoring germplasm to source countries when national collections are lost due to natural and human-induced calamities. A number of germplasm accessions/selections are released as superior varieties through partnership research. Moreover, over 66 germplasm accessions supplied from the ICRISAT genebank have been directly released as cultivars in 44 countries.

Plant biotechnology at ICRISAT

ICRISAT's application of biotechnology encompasses plant tissue culture, plant molecular markers, and genetic engineering. These applications range from the simple to the sophisticated, and are in many cases appropriate for use in developing countries. ICRISAT considers plant biotechnology to be a tool that may allow the breaking down of old barriers to high crop productivity. The overall goal of ICRISAT's Global Theme on Harnessing Biotechnology for the Poor is to reduce poverty, hunger, malnutrition, and environmental degradation in SAT by applying and integrating wide-hybridization, applied genomics, genetic engineering, and diagnostic and bioinformatics tools and approaches with conventional genetic enhancement. Its aim is to improve the efficiency, effectiveness, speed, and precision of plant breeding for abiotic stress tolerance; pest and disease resistance; better agronomic traits, improved food, feed, and fodder quality; and to develop diagnostic tools for the detection of plant viral infections, toxic contaminants in crops and crop-based products, and the purity of seed production systems.

Applied genomics

Applied genomics and molecular marker technology are useful in assisting and speeding up selection through conventional breeding. It is a powerful method for identifying the genetic basis of traits and is used to construct linkage maps to locate particular genes that determine beneficial traits. Using molecular markers, genetic maps of great detail and accuracy have been developed for many crop species. These markers are particularly useful for analyzing the influence of complex traits like plant productivity and stress tolerance and are being employed to develop suitable cultivars of major crops.

Molecular marker information, complemented by good quality phenotyping, can greatly facilitate the appropriate choice of parents for crosses. Molecular markers are almost infinitely superior to conventional morphological marker genes for mapping or tagging gene blocks associated with economically important traits, whether these are inherited in a simple Mendelian fashion (e.g., the d2 dwarfing gene in pearl millet; Azhaguvel, Hash, Rangsamy et al. 2003) or inherited in a more complex manner [e.g., QTL (quantitative trait loci) controlling the stay-green trait in sorghum; Haussmann, Mahalakshmi, Reddy, et al. 2002]. Gene tagging and QTL mapping in turn permit MAS (marker-assisted selection) in back-cross, pedigree, and population improvement programmes, which are useful for crop traits that are otherwise difficult or impossible to deal with by conventional means (e.g., due to difficulties in obtaining repeatable field, greenhouse, or laboratory screening conditions 'on-demand' as a result of a natural variation in rainfall or pest pressure, or due to phytosanitary restrictions).

ICRISAT has a high throughput applied genomics laboratory and uses MAS as a potential method to hasten and improve the precision and effectiveness of crop improvement. Molecular markers have been identified for the stay-green trait and resistance to shoot fly and Striga in sorghum and downy mildew resistance and terminal drought tolerance in pearl millet. Research is on to identify markers for root mass and resistance to Ascochyta blight, botrytis gray mold, and Helicoverpa pod borer in chickpea; and Fusarium wilt resistance and fertility restorer genes in pigeonpea. A high throughput DNA marker-screening laboratory has been established at ICRISAT, Patancheru to strengthen our capacity in molecular breeding with particular reference to liberating the value encapsulated in our germplasm collections.

Substantial progress has been made in the development of tools for mapping important agronomic traits in chickpea, groundnut and pigeonpea, apart from major advances in the molecular breeding of sorghum and pearl millet. Two pearl millet hybrids having parental lines bred by MAS for downy mildew resistance have been developed at ICRISAT. In January 2005, the Haryana State Varietal Release Committee released one of these, HHB 67-2, for commercial cultivation. This is the first public sector-bred marker-assisted pearl millet breeding product to be released and is the crowning achievement of 15 years of investment in pearl millet marker assisted breeding by ICRISAT, the Indian national program, UK-based partners and the UK's Department For International Development in Plant Sciences Research Programme.

Activities at ICRISAT also focus on the application of high throughput marker technology for genetic diversity assessment, QTL mapping, and marker-assisted breeding. Among the global projects are those pertaining to the improvement of abiotic stress tolerance, agronomic and quality traits, and the use of agro-biodiversity through the application of genomics and bioinformatics.

Genetic engineering of crops

Non-sexual DNA transfer techniques enable manipulations that are outside the repertoire of breeding or cell fusion techniques (Sharma and Ortiz 2000). Genes can be accessed from exotic sources — plant, animal, bacterial, even viral — and introduced into a crop. Since the DNA elements that control gene expression can, and often must, be modified for proper function in the new host, it is possible to control timing, tissue specificity, and the expression level of transferred genes. Endogenous plant genes may even be reprogrammed through the reintroduction of an engineered gene. Many of the modifications being carried out, or envisaged, are for disease, pest, or herbicide resistance. These possibilities allow the introduction into crop plants of genes that have previously been inaccessible to the conventional plant breeder, or which did not exist in the crop of interest. However, the non-availability of efficient transformation methods to introduce foreign DNA can be a substantial barrier to the application of recombinant DNA methods in some crop plants (Birch 1997; Sharma, Bhatnagar-Mathur, and Thorpe 2005).

Despite significant advances over the past decade, development of efficient transformation methods can take many years of painstaking research. Effective regeneration and transformation systems are prerequisites for successful genetic transformation (Sharma and Ortiz 2000; Sharma, Bhatnagar-Mathur, and Thorpe 2005). Stable engineered resistance requires the production of numerous independent transformants to allow the selection of those with the appropriate level of gene expression.

Genetic transformation technology relies on the conceptual framework and the technical approaches of plant tissue culture and molecular biology to develop commercial processes and products. The major components for the development of transgenic plants (Birch 1997) are: (1) development of reliable tissue culture regeneration systems, (2) preparation of gene constructs and transformation with suitable vectors, (3) efficient techniques of transformation for the introduction of genes into crop plants, (4) recovery and multiplication of transgenic plants, (5) molecular and genetic characterization of transgenic plants for stable and efficient gene expression, (6) transfer of genes to elite cultivars by conventional breeding methods if required, (7) evaluation of transgenic plants for their effectiveness in alleviating biotic or abiotic stresses and field performance, (8) biosafety assessment including food and environmental safety, and (9) commercialization of GE (genetically engineered) crop.

Efforts have been made at ICRISAT to develop in vitro tissue culture and transformation systems for the production of transgenic plants. A major emphasis has been on developing transformation systems that are efficient, reproducible, and can be successfully transferred to partners in NARS (national agricultural research systems). ICRISAT has pioneered transformation technologies for all its mandate crops by developing tissue culture and transformation methods based on Agrobacterium-mediated gene transfer for groundnut, pigeonpea, and chickpea and for sorghum through biolistics, which are now available for routine applications.

A large number of transgenic plants carrying genes for resistance to viruses (groundnut); insect pests (pigeonpea, chickpea, and sorghum); fungal pathogens (groundnut, pigeonpea, and chickpea); tolerance to drought stress (groundnut and chickpea); and nutritional enhancement (groundnut and pigeonpea) are being produced and characterized. These transgenics are in different generations, and are being studied for gene expression and inheritance, and their efficacy against their respective constraints. During the rainy season of 2002, ICRISAT carried out the first-ever contained field-testing of transgenic groundnut for resistance to the Indian peanut clump virus at Patancheru, India; this was repeated during 2003–05 to select promising events. In addition, the first contained field-testing of transgenic pigeonpea and chickpea for insect resistance were carried out in 2003 and 2004, respectively. Besides this, GRAV (groundnut rosette virus), PBNV (peanut bud necrosis virus), and peanut stem necrosis disease are being addressed through transgenic approaches. Work is also on to develop transgenics in groundnut and chickpea for tolerance to abiotic stresses such as drought and low temperatures where the transgenics carrying transcription factors like DREB (Drought responsive element binding protein) and osmoregulatory proline-overproduction genes are currently being tested in greenhouse studies. In cereals, transgenics have been developed for resistance to stem borer in sorghum and are currently under greenhouse testing.

Today, more than 700 million people in developing countries do not have access to sufficient food to lead healthy and productive lives. More than 180 million children are underweight. As many as 500 000 preschool children go blind each year as a result of vitamin A deficiency. Lack of micronutrients such as vitamin A and iron not only causes suffering and death but also cuts deeply into the productivity. Through research and policy, diets could be changed to eliminate much of this suffering. Biofortification of crops is a promising tool against malnutrition. ICRISAT's nutrition orientation is demonstrated in four major research initiatives such as biofortification with Zinc, Iron and Vitamin A in sorghum and pearl millet; Zinc and Iron in pigeonpea, and Vitamin A in groundnut. These initiatives harness new scientific knowledge, methods, and techniques to enhance the nutritive value of food cereals and legumes.

GE offers plant breeders access to a wide array of novel genes and traits which can be inserted through a single event into high-yielding and locally adapted cultivars. This approach offers rapid introgression of novel genes and traits into elite agronomic backgrounds. Future impacts of biotechnology in crop production will be in the areas of: (1) developing new hybrid crops based on genetic male-sterility, (2) exploiting transgenic apomixis to fix hybrid vigour in inbred crops, (3) increasing resistance to insect pests, diseases, and abiotic stress factors, (4) improving effectiveness of biocontrol agents, (5) enhancing the nutritional value (vitamin A and iron) of crops and the post-harvest quality, (6) increasing the efficiency of soil phosphorus uptake and nitrogen fixation, (7) improving adaptation to soil salinity and aluminum toxicity, (8) understanding the nature of gene action and metabolic pathways, (9) increasing photosynthetic activity, sugar, and starch production, and (10) producing pharmaceuticals and vaccines.

With the experience gained in developing transformation technologies for our mandate crops, carrying out contained field-testing at Patancheru, studying the food and environmental safety of the transgenic plants, communicating biotechnology to the media, and transfer of technology through training, we are in a strong position to undertake such activities in partnership with NARS and private sector in India, and in other regions of Asia and Africa. This will enable ICRISAT to develop appropriate strategies for testing its transgenic crops under contained and open field conditions, and their possible deployment through the development of biosafety and commercialization packages in the near future (Sharma, Sharma, Seetharama, et al. 2002). This will allow us to effectively use transgenic technology in conjunction with conventional plant breeding for sustainable crop improvement in the SATs.

Risk assessment and biosafety considerations

Modern biotechnology has the potential to lead to considerable advances in agriculture. Over the recent years, these technological advances have revolutionized our ability to alter life-forms through GE or fusion of cells beyond the taxonomic family, which overcome natural physiological reproductive or recombination barriers, and which are not techniques used in traditional breeding and selection. At the same time, many of the risks of modern biotechnology (such as potential adverse effects on biological diversity and risks to human health) are not yet known. Risk assessment of the products of biotechnology must therefore be strictly performed and precautionary principles should be considered in the decision-making process. Risk assessment comprises hazard identification, hazard characterization, exposure assessment, and risk characterization.

Biotechnological research at ICRISAT favours a sustainable diversified agriculture, including agricultural biotechnology, making special efforts to help the resource-poor farmers of SAT. However, at the same time, key issues such as biosafety regulations, risk assessment and management, IPR (intellectual property rights), and other scientific, technical, environmental, regulatory, and policy-making issues are dealt with a great deal of sensitivity. The safety of transgenic material is a major concern, and in order to address public concerns on GM (genetically modified) food, utmost importance is being given to the established regulatory systems. All biotechnology programmes abide by the legally established regulations of the country where the research is being conducted. A special IBSC (Institutional Biosafety Committee) has been established to prepare for the testing of genetically improved material. Biosafety guidelines are strictly followed for the evaluation and eventual clearance of the development and deployment of transgenic crops. The transgenic material being developed at ICRISAT meets the approval of IBSC, RCMG (Review Committee on Genetic Manipulation) and GEAC (Genetic Engineering Approval Committee). ICRISAT works closely with the host countries in determining proper risk analysis for the field-testing of GM crops.

New initiatives

ICRISAT is actively involved in all three challenge programmes of CGIAR (Consultative Group on International Agricultural Research). In the HarvestPlus Challenge Programme, it is working on improving the pro-vitamin A content of groundnut and pigeonpea by increasing the ß-carotene level using GE, enhancing the nutritional quality of pigeonpea for sulphur-rich amino acids using GE, and improving the micronutrient content in sorghum using genomics. Under the Generation Challenge Programme, ICRISAT projects include the assessment of molecular diversity in sorghum, pearl millet, chickpea, pigeonpea and groundnut; marker-assisted improvement of drought tolerance in sorghum, pearl millet, and chickpea; GE of drought tolerance in groundnut; and the development of various bioinformatics tools. In the Water and Food Challenge Programme, ICRISAT is using molecular markers to back-cross the stay-green trait into early-maturing sorghum varieties for West Africa.

ICRISAT has established effective partnerships to tackle the aflatoxin problem. In partnership with national and state governments in India and countries in West Africa, ICRISAT is disseminating the technology to detect aflatoxin contamination in farm produce. It includes inducing awareness among producers, traders, and consumers about issues of economic significance, including risks to health and good prices for quality products; selecting low-cost biocontrol agents; developing cost-effective agronomic practices; identifying genotypes that resist contamination by conventional and non-conventional methods at the farm level, and promoting the technologies among both marginal farmers and commercial holdings to improve the production of quality nuts. ICRISAT has developed and standardized a low-cost kit for detecting aflatoxin contamination in crops such as groundnut, corn, chillies, etc. Using the regular ELISA (enzyme-linked immunosorbent assay) method, ICRISAT scientists have developed and standardized an antibody and the protocol whereby the cost of aflatoxin detection can be drastically reduced from around 25 dollars per sample to 1.5 dollars per sample.

ICRISAT has made considerable progress in salinity-tolerance research in terms of assessing genetic variability, identifying tolerant germplasm lines, varieties, hybrid parents, and breeding lines; and identifying possible mechanisms of salinity tolerance that could enhance breeding efficiency. An OPEC (Organization of Petroleum Exporting Countries) Fund for International Development-supported initiative to develop salinity-tolerant sorghum and pearl millet in collaboration with the ICBA (International Centre for Biosaline Agriculture) Dubai, started in 2002, has identified 17 sorghum and 11 pearl millet entries showing high tolerance to salinity, and 15 sorghum and 26 pearl millet entries that were very sensitive. Several of the widely cultivated varieties and parental lines of hybrid sorghum were found to be tolerant to soil salinity. For example, variety ICSV 112 has been released and adopted in many countries in Asia, Africa, and Latin America; drought-tolerant variety S 35 is popular in Western and Central Africa; and a post-rainyseason variety, NTJ 2, is also known for its fodder. Non-destructive methods of measuring salinity tolerance are being investigated to phenotype mapping populations. Identification of molecular markers for salinity tolerance, which has not yet been achieved for pearl millet and sorghum, is in progress.

The bioinformatics facility at ICRISAT has effectively used a combination of open source sequence analysis tools and parsing tools written inhouse to analyze ESTs (expressed sequence tags) from biologically and agronomically relevant tissues in chickpea sequenced at ICRISAT, along with genomic sequences from groundnut and pigeonpea. The analysis protocol has allowed putative functional identification for most of the sequences, which have then been deposited into the public nucleic acid database—Genbank.

Public–private sector partnerships

Market failure in the developing world is compounded by the absence of technology transfer mediator mechanisms. These constitute significant disincentives for private investment and innovation in biotechnology. In this regard, the effectiveness of biotechnology is crucially dependent upon actions that strengthen the capacity of public and private research systems. Our efforts to apply science to the problems of the world's poorest are characterized by joint efforts with the public and private sectors. ICRISAT acts as a catalyst, bridge, and scientific contributor, helping advanced research institutions adapt and deliver their novel techniques and information to solve the pressing problems of the Semi Arid Tropics (SAT). Agri-Science Park in ICRISAT is a 'hub' for facilitating public–private partnerships, which enhances the development and commercialization of science-generated technologies and knowledge through market mechanisms. ASP facilitates these partnerships through several mechanisms that include AIC (Agbiotech Innovation Centre) and ABI (Agri-Business Incubator) which hosts about 12 partners. Besides, it also provides support for other partnerships with the private sector through the development of consortia for specific activities.

Agbiotech Innovation Centre

AIC is a venture in which mature businesses can establish facilities to tap into ICRISAT's upstream research expertise and use its world-class infrastructure either on a contract basis or through joint ventures. The scientific resources and support services available in ASP include access to an international body of expert scientists, genetic transformation and applied genomics laboratories, containment greenhouses, bioinformatics facility, and assistance on IPRs and biosafety issues.

Agri-Business Incubator:

Another unit of ASP, ABI enables startup agri-business companies to tap the research innovations of ICRISAT and its development partners, and their scientific and managerial support resources to grow and develop into viable ventures. Funded through a collaborative project between ICRISAT and the DST (Department of Science and Technology), Government of India, ABI provides infrastructural support, technology exchange, feasibility studies, networking, and training facilities. While dealing with various aspects of agri-business, it currently supports eight companies and was recently adjudged the best Technology Business Incubator by the Government of India for 2005.

Public–Private Sector Consortia

ICRISAT recognizes the advantages of the complementarity of agendas and acknowledges that its partners are the cornerstone of its operations. This has led to the formation of the Sorghum and Pearl millet Hybrid Parents Research Consortia, the first of its kind in the entire CGIAR system. Under this arrangement, each member contributes a small research grant each year for sorghum and pearl millet research for a five-year period. The consortium has 16 members from private sector seed companies for sorghum, 26 for pearl millet, with 11 being common for both the crops by the end of 2003.

In a similar approach, ICRISAT has also facilitated the development of an Improved Pigeonpea Hybrid Seed Consortium for research leading to the development of hybrid pigeonpea based on the CMS (cytoplasmic male sterility) system. This involves 11 private seed companies, ICAR (Indian Council of Agricultural Research), and the Ministry of Agriculture, Government of India. Currently, CMS lines have been developed, fertility restorers identified, and CMS-derived pigeonpea hybrids in early- and medium-duration pigeonpea have been showing 50%–100% yield advantage at the experiment station.

BRC (Biopesticides Research Consortium) is meant to develop, promote, and commercialize the use of biopesticides by farmers. ICRISAT and its national partners have been working on bacterial isolates, fungi, and entomopathogenic viruses to manage insect pests and diseases. The partnership research will validate protocols for low-cost, commercial-scale production of microbial biopesticides developed at ICRISAT, and will promote agricultural practices that enable protection of crops at a low cost. To date, BRC has 11 biopesticide manufacturers as members. Besides, ANGRAU (Acharya NG Ranga Agricultural University) and ICRISAT have developed a programme to provide technical backstopping for MAS for rice at ICRISAT.

Communicating biotechnology

Biotechnology holds the key to food sufficiency and security, however the public has not accurately understood it. There is public suspicion and resistance to the use of biotechnology in improving plants, and therefore there is a need to inform and educate the public about it. At ICRISAT, however, the major emphasis is on connecting scientists with the public. Here, communication is regarded as a major link between global research themes and their impact. Besides, innovative and strategic communication initiatives are being pursued to inform, educate, and mobilize key stakeholders to utilize ICRISAT's agricultural innovations like agri-biotechnology. ICRISAT networks with the media and shares cutting edge innovations and IPGs (international public goods) through ICTs (information and communication technologies) and ODL (open-distance learning). Besides generating global public goods, ICRISAT works to generate and promote science and facilitate its communication to a broad array of stakeholders. This allows them to make informed decisions about such products and biosafety based on timely information and knowledge. Under the Andhra Pradesh R&D Fund grant, VASAT (Virtual Academy for the Semi-Arid Tropics) and MSSRF (MS Swaminathan Research Foundation) have developed a programme to train farmers in Andhra Pradesh in the use of biotech products and biosafety. They have also conducted a series of media workshops on biotechnology with partners in New Delhi, Niamey, and Bangladesh.

Commercializing products of biotechnology

ICRISAT's biotechnology research also involves the effective exploitation of existing knowledge, in addition to generating new knowledge. With a biological revolution in progress and a fund of information about the genetics of plants being accumulated, the task remains to turn this into the knowledge and technologies needed to improve the yield of the world's major crops and a tool in achieving the second Green Revolution. It is essential that agricultural biotechnology research is relevant to the needs of farmers in developing countries, and that the benefits of the research are transmitted to small-scale farmers and consumers in those countries at affordable prices (Sharma, Sharma, Seetharama et al. 2002). Condemning biotechnology for its potential risks without considering the alternative risks of prolonging human misery caused by hunger, malnutrition, and infant mortality is unwise and unethical. Genetically improved foods need to be developed under adequate regulatory processes with full public understanding. At the same time, an increased understanding and acceptance of research tools that draw on farmers' participation could help target research outputs to particular environmental and socioeconomic niches.

Conclusions

ICRISAT adopts a balanced perspective in the conduct of its research in biotechnology by undertaking activities within the framework of existing national and global research agendas and priorities. This has resulted in a continuous commitment to tackle global hunger, poverty, and malnutrition. Agricultural biotechnology is undoubtedly a strategic weapon in achieving the 'Grey to Green Revolution' and in enabling the second Green Revolution. The use, assimilation, and adaptation of biotechnological tools should be an integral part of agricultural research. Biotechnology-derived solutions to agricultural problems, if built into the genotypes of plants, could reduce the need for water as well as the deleterious effects of diseases and pests, thus promoting sustainable agriculture. Biotechnological methods are not an end in themselves but powerful tools for research and ultimately for accelerating development. They are critical in overcoming the severe bottlenecks associated with conventional agricultural programmes and enhancing their delivery prospects. So, they need to be used as adjuncts to and not as substitutes for conventional technologies. Finally, let us harness biotechnology with due regard for the consumer and the environment.

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